Virtual Testing Protocols and LS-DYNA – Pre and Post Processing Solutions in the Oasys LS-DYNA Environment

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1 Abstract

The Oasys LS-DYNA Environment is a key part of many LS-DYNA workflows, used to ensure quality models and results.

The introduction of virtual testing crashworthiness (VTC) protocols is changing how CAE teams create and process LS-DYNA crash models and poses several challenges for CAE workflows. Good correlation is moving from beneficial to mandatory, and we can no longer rely on conservative assumptions. The format and quality of outputs is increasingly important to meet the requirements of regulatory bodies. CAE teams will need to work more with physical test data, and safety teams will need to work more with simulation data – how do we improve collaboration and processing? How can we manage large amounts of data for virtual testing?

At Oasys Ltd., we are working on software solutions to support the upcoming virtual testing protocols. The Oasys LS-DYNA Environment contains a set of integrated and complementary Workflow tools to provide a comprehensive solution for CAE and vehicle safety teams as they face the new challenges of virtual testing protocols. These include:

- VTC Quality Criteria tools for automated monitoring of LS-DYNA model quality in accordance with Euro NCAP and C-NCAP protocols
- Automotive Assessments tool for automatic mapping of LS-DYNA model entities to sensor channels, managed for vehicle programs via workflow user data
- SimVT: a powerful tool for correlating any combination of LS-DYNA, ISO-MME or CSV data according to virtual testing protocol requirements
- A workflow tool to convert LS-DYNA data to the ISO-MME format required by Euro NCAP
- Assisted camera-positioning and automated export of the video files required by the Euro NCAP and C-NCAP protocols

This paper will demonstrate the functionality of these tools, and how they address the challenges faced by CAE teams designing vehicles to meet virtual testing protocol requirements.

2 Introduction

Historically, vehicle crashworthiness regulations and New Car Assessment Program (NCAP) safety ratings have been based on physical testing alone. This is changing with the advent of virtual testing protocols. Virtual testing protocols aim to improve overall vehicle safety by testing the sensitivity of vehicle designs to a wider range of conditions, while minimizing the cost of physical testing [1][2].

In virtual testing, a simulation model is validated against a physical test and then – if the validation is deemed acceptable – variations of the test are rated based on simulation results called “virtual loadcases”. Initially, these virtual loadcases will consider variations in impact angle or occupant seating position. In time, they will accommodate the introduction of human body models to augment the traditional use of anthropomorphic test devices (ATDs) [1][2]. Virtual loadcases aim to improve the safety of vehicles in a greater number of representative real-world scenarios, and for a more diverse range of human anthropometries.

Virtual testing promises significant improvements in vehicle safety, but it also represents a new paradigm for the vehicle safety industry and especially for LS-DYNA users. Previously, computer-aided engineering (CAE) teams used LS-DYNA to predict the behavior of vehicle designs in preparation for the physical crash test assessment. With virtual testing, LS-DYNA simulation is part of the actual

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assessment. For LS-DYNA users, this is like switching from doing homework to prepare for an exam, to being in the exam hall doing the final exam: the stakes are higher, and the consequences greater.

The Oasys LS-DYNA Environment is a key part of the overall CAE workflow for many LS-DYNA users, widely used to ensure quality models and results [3]. This paper presents the authors' method of reviewing the requirements of virtual testing protocols and identifying the various challenges they present. The Oasys LS-DYNA Environment software solutions developed in response to these challenges are then described.

3 Method

A review was conducted into the requirements of the virtual testing protocols published to date [4][5], in conjunction with insights and priorities gathered from interviews and discussions with many close industry partners. From this review, a set of new challenges was identified for the CAE and vehicle safety departments of original equipment manufacturers (OEMs) and their suppliers. Solutions to address these challenges were then developed for the Oasys LS-DYNA Environment software.

3.1 Protocol Requirements

Although there are differences between the requirements of the various regulatory and NCAP protocols, the virtual testing protocols published to date [4][5] share some common requirements that can be grouped into the following categories:

3.1.1 Quality

In order to provide a meaningful basis for validation against physical test data, LS-DYNA simulation models must meet a set of quality criteria, including limits imposed on hourglass energy, mass scaling, stability of initial conditions, and termination time.

3.1.2 Correlation

The main method of validation is an objective comparison of time-history signals from various sensors placed on the ATDs and vehicle structures in the physical test, and their corresponding entities in the LS-DYNA model. For both the Euro NCAP and C-NCAP protocols [4][5], this assessment of "correlation" must be completed according to ISO/TS 18571:2024 [6].

3.1.3 Injury Assessment

Vehicle safety protocols specify injury assessment criteria, typically in the form of limits or scores assigned to the force, deformation, and acceleration signals recorded by the ATDs. In virtual testing protocols, these metrics are compared between simulation and physical data as part of the validation requirement.

In the Euro NCAP protocol, Validation Criterion 2 (VC2) imposes an acceptability limit on the differences d_{AC} between the ratios of the injury metrics and their limits when compared between simulation and physical test:

Validation Criterion 2 (Assessment Criteria): $d_{AC} < 30\%$

The C-NCAP protocol specifies a correction factor A based on the ratios of the injury metrics and their limits, and applies it to the overall protocol score calculation:

$$\text{Overall score} = \frac{(Overall\ score)_{Working\ condition,physical\ test} + \sum_i^7 \{A * (Overall\ score)_{Virtual\ test,i}\}}{8}$$

3.1.4 Data Submission

In order to ensure integrity of the assessment, simulation results are required to be submitted to the testing authority in advance of the physical tests. Euro NCAP requires the submission of results data in

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ISO-MME format [7], whereas C-NCAP is less specific, and indicates that LS-DYNA binout files are also acceptable.

Both virtual testing protocols also require the submission of videos showing animations of the simulations viewed from a specified set of camera angles.

3.2 Industry Challenges

The protocol requirements described in section 3.1 present significant new challenges for OEMs and their suppliers:

3.2.1 Good correlation has become mandatory

Good correlation between LS-DYNA models and physical tests has always been beneficial in the vehicle design process. However, before the advent of virtual testing, CAE teams could rely on making conservative assumptions in their LS-DYNA models. Previously, engineering for redundancy was a workable strategy. But now, it is no longer acceptable if the physical test performs better than predicted. It must perform exactly as predicted – or within the protocol limits.

CAE and vehicle safety teams need new correlation tools to perform rapid and accurate correlation analysis, with the ability to analyze and investigate causes of poor correlation.

3.2.2 Collaboration between CAE and Vehicle Safety teams

OEM departments set targets for many different vehicle attributes, including design, performance, handling, manufacturing, safety, and cost. Vehicle safety teams are the main stakeholders for the vehicle safety attributes. They work with test houses to perform the physical tests required by protocols and regulations, and they work with CAE teams to ensure that the safety targets will be achieved. With the advent of virtual testing, CAE teams will need to work more with physical testing data, and vehicle safety teams will need to work more with simulation data. They will also be working with many more metrics than previously. New tools are needed to aid this increased communication and collaboration.

3.2.3 Quantity of LS-DYNA analysis

The virtual testing protocols specify a larger number of loadcases to be analyzed, resulting in a significant increase in the volume of data to be managed. Virtual testing software solutions should be designed to facilitate this increased volume of data processing and storage.

3.2.4 Format and quality of data

The protocol requirements place increased responsibilities on CAE and vehicle safety teams to ensure that the quality of their LS-DYNA models is sufficient and that the format of the data submitted is correct. Tools are needed to aid model quality checking and reformatting so that data submission is successful.

4 Solutions

Virtual testing solutions were developed for the Oasys LS-DYNA Environment software. The Oasys LS-DYNA Environment is a key part of the overall CAE workflow for many LS-DYNA users, widely used to ensure quality models and results.

The Oasys LS-DYNA Environment now contains a set of integrated and complementary Virtual Testing tools [8] to provide a comprehensive solution for CAE teams as they face the new challenges of virtual testing protocols:

1. Automotive Assessments
2. LS-DYNA to ISO-MME
3. SimVT
4. VTC Quality Criteria
5. VTC Videos

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The Oasys LS-DYNA Environment supports the published Euro NCAP and C-NCAP virtual far side impact protocols, and the solutions have been developed in a way that will facilitate support for the various other protocols due to be published in the coming years. The following sections describe the solutions that were developed for each of the protocol requirements and explain how they address the challenges identified.

4.1 Workflows

Many LS-DYNA pre- and post-processors offer a range of tools that can be used to configure and interrogate LS-DYNA models. However:

- The basic tools are not always customized for LS-DYNA, or for specific loadcases
- Many manual steps may need to be performed to process results, which can be time-consuming and prone to error
- Scripting APIs can be used to create tools to automate tasks, but this requires time, resource and knowledge, which is not always available

For these reasons, the Oasys LS-DYNA Environment virtual testing solutions were developed within the existing Workflows framework [9]. Workflows is a powerful framework that provides Oasys LS-DYNA Environment users with customized tools that work seamlessly from pre-processing through to post-processing, providing results quickly and reliably. While building LS-DYNA models in the pre-processor, Oasys PRIMER, Workflows enables CAE teams to tag models with “user data” which is leveraged in the post-processors: Oasys D3PLOT, Oasys T/HIS and Oasys REPORTER to surface relevant results and insights.

4.1.1 Workflow User Data

Workflow user data can be saved to LS-DYNA keyword files (below the **`*END`** keyword) or as separate JavaScript Object Notation (JSON) files. Saving to the keyword files has the benefit that the user data is linked directly to the model. Alternatively, the Oasys LS-DYNA Environment will automatically locate relevant user data in JSON files located in the same directory as the LS-DYNA model, or in parent directories. This option is particularly powerful, because it only requires Oasys LS-DYNA Environment users to save user data once, and then those data can be reused throughout a vehicle design program, for multiple LS-DYNA models and loadcase variants.

```
- cae_team_analysis_directory_1
   |- workflow_user_data_directory
   |     |- workflow_1_user_data.json
   |     |- workflow_2_user_data.json
   |     |- workflow_3_user_data.json
   |
   |- loadcase_directory_1
   |     |- LS-DYNA_job_directory_1
   |           |- model1.key
   |           |- d3thdt
   |           |- d3plot
   |     |- LS-DYNA_job_directory_2
   |           |- model2.key
   |           |- d3thdt
   |           |- d3plot
   |
   |- loadcase_directory_2
   |     |- LS-DYNA_job_directory_3
   |           |- model3.key
   |           |- d3thdt
   |           |- d3plot
```

Fig.1: An example CAE team analysis file directory structure in which user data stored in a nominated “workflow_user_data_directory” is automatically located by models in child or grandchild directories (or great-grandchild directories, etc.)

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Given the large quantity of LS-DYNA analysis required for virtual testing, it is essential to have a convenient system for managing user data at scale. Accordingly, Oasys LS-DYNA Environment users are given flexibility and control over Workflow user data management. Application preferences provide control over the number of upwards directories that will be searched for user data files, and flexibility is permitted in the name of the directory used to store user data. In this way, CAE teams can incorporate user data seamlessly into their LS-DYNA analysis storage without contravening their organization's simulation data management rules or requirements.

4.1.2 Automotive Assessments

To provide greater flexibility, the individual protocol requirements are separated into distinct workflow tools. However, they all share some common parameters, which are defined in the Automotive Assessments workflow tool. For LS-DYNA users, this is the starting point for virtual testing:

1. In the Automotive Assessments tool, select the crash test of interest
2. Confirm the occupant and structures metadata
3. Save as user data

Thereafter, the other Workflow tools automatically adopt this user data, saving the need for it to be redefined repeatedly.

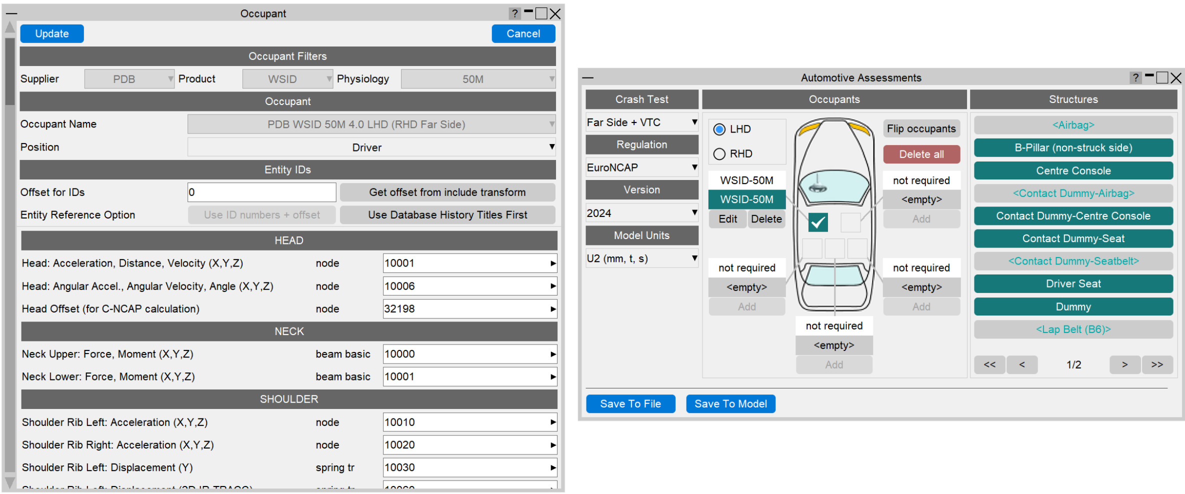

Fig.2: The Automotive Assessments workflow viewed in Oasys PRIMER, showing LS-DYNA model entities mapped automatically to occupant parameters

4.2 Quality

In the Oasys LS-DYNA Environment, the Euro NCAP and C-NCAP VTC Quality Criteria workflow tools enable CAE teams to perform the quality checks outlined in Section 6.1 of the Euro NCAP protocol [4] and Section H.1.1(f) of the C-NCAP protocol [5].

In Oasys PRIMER, the VTC Quality Criteria workflows automatically collect data saved previously in the Automotive Assessments workflow to identify the relevant LS-DYNA model entities, including lists of `*PART` keywords for the seat and the ATD, as well as `*NODE` keywords to define the locations of the B-pillar, H-point and ATD head sensors. Once saved as user data for their vehicle program, CAE teams can generate a VTC Quality Criteria report at the end of each LS-DYNA job using the automation application Oasys REPORTER.

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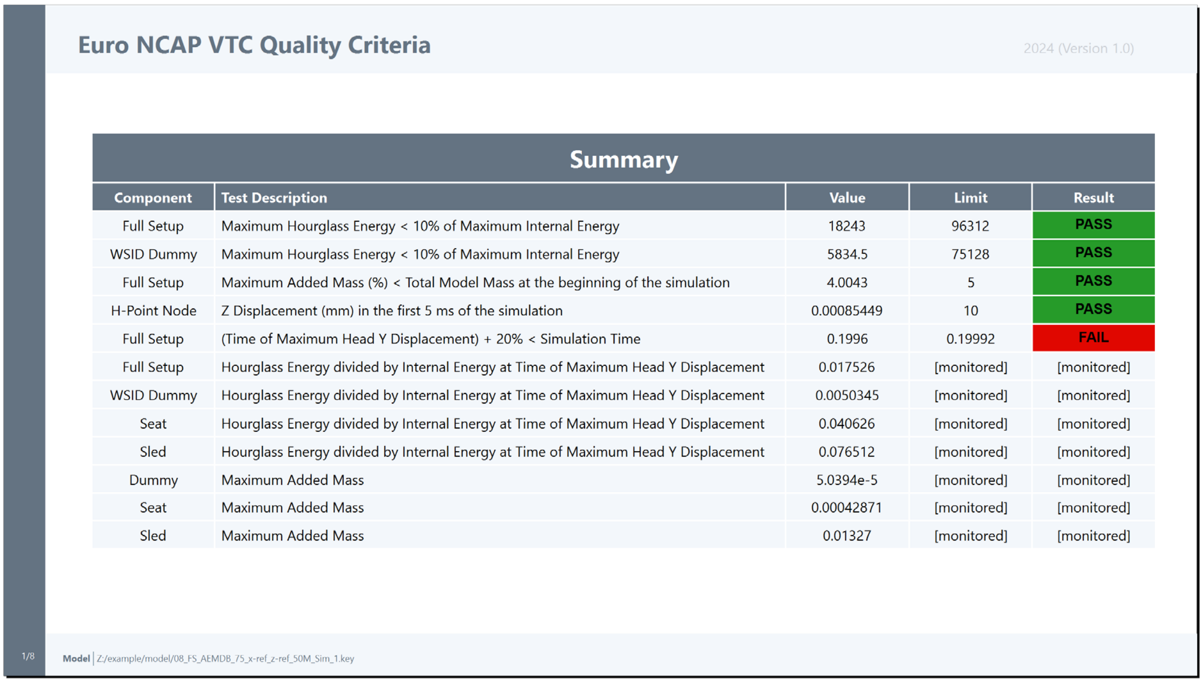

Euro NCAP VTC Quality Criteria

2024 (Version 1.0)

Summary				
Component	Test Description	Value	Limit	Result
Full Setup	Maximum Hourglass Energy < 10% of Maximum Internal Energy	18243	96312	PASS
WSID Dummy	Maximum Hourglass Energy < 10% of Maximum Internal Energy	5834.5	75128	PASS
Full Setup	Maximum Added Mass (%) < Total Model Mass at the beginning of the simulation	4.0043	5	PASS
H-Point Node	Z Displacement (mm) in the first 5 ms of the simulation	0.00085449	10	PASS
Full Setup	(Time of Maximum Head Y Displacement) + 20% < Simulation Time	0.1996	0.19992	FAIL
Full Setup	Hourglass Energy divided by Internal Energy at Time of Maximum Head Y Displacement	0.017526	[monitored]	[monitored]
WSID Dummy	Hourglass Energy divided by Internal Energy at Time of Maximum Head Y Displacement	0.0050345	[monitored]	[monitored]
Seat	Hourglass Energy divided by Internal Energy at Time of Maximum Head Y Displacement	0.040626	[monitored]	[monitored]
Sled	Hourglass Energy divided by Internal Energy at Time of Maximum Head Y Displacement	0.076512	[monitored]	[monitored]
Dummy	Maximum Added Mass	5.0394e-5	[monitored]	[monitored]
Seat	Maximum Added Mass	0.00042871	[monitored]	[monitored]
Sled	Maximum Added Mass	0.01327	[monitored]	[monitored]

1/8 Model | Z:/example/model/08_FS_AEMDB_75_x-ref_z-ref_50M_Sim_1.key

Fig.3: Summary page of the Euro NCAP VTC Quality Criteria report generated by Oasys REPORTER

As well as a summary page showing the overall VTC Quality Criteria results, the report contains graphs for each of the quality criteria, with colored datums to indicate clearly whether individual quality criteria have been met. LS-DYNA users can also open post-processor Oasys T/HIS to view the VTC Quality Criteria results in an interactive session for more detailed inspection and investigation.

The VTC Quality Criteria workflow tools in the Oasys LS-DYNA Environment provide a simple and effective method for ensuring that LS-DYNA model quality meets specified criteria, saving CAE teams time in their virtual testing analysis work.

Fig.4: Euro NCAP VTC Quality Criteria workflow in Oasys T/HIS showing graphs of processed LS-DYNA results data.

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4.3 Correlation with SimVT

A key requirement of virtual testing protocols is to prove that the LS-DYNA model is representative of reality. To achieve this, OEMs face the challenge of correlating many LS-DYNA output channels (such as head accelerations) with the corresponding physical test data.

The Oasys LS-DYNA Environment solution for correlation analysis is SimVT. The SimVT workflow is so named because makes it easy for users to perform the required **sim**ulation **v**ersus **t**est correlations as specified in **V**irtual **T**esting protocols. SimVT empowers users to perform many correlations with just a few clicks.

SimVT solves the challenge of achieving good correlation between LS-DYNA simulation and physical test. With SimVT, Oasys LS-DYNA Environment users can view reports of correlation results with ease, using the time-saving templates preconfigured for each protocol. By using SimVT's options to process time-history data stored in a range of formats, both CAE and vehicle safety teams can use SimVT to interrogate correlation results in detail, and work together to identify any changes needed to ensure targets are achieved.

The following sections describe the features of SimVT that empower Oasys LS-DYNA Environment users to meet the challenges of virtual testing correlation analysis.

4.3.1 Correlation Setup

The SimVT workflow is run in the post-processor Oasys T/HIS and opens with the SimVT Correlation Setup window which is used to:

- Import additional data sources
- Select the reference data source (typically physical test data)
- Select one or more simulation data sources to correlate against the reference data
- Configure SimVT for a selected virtual testing protocol
- Configure the correlation method and evaluation intervals
- Apply channel matching rules
- Select the channels to correlate

Channel data from multiple sources such as ISO-MME, CSV and LS-DYNA models are supported, making the tool versatile and flexible. SimVT can be used to compare any combination of simulation-versus-simulation, simulation-versus-test, or test-versus-test data, enabling both CAE and vehicle safety teams to interrogate their data sources and work together to achieve correlation targets.

For LS-DYNA models with user data saved previously via the Automotive Assessments workflow in Oasys PRIMER, the LS-DYNA model entities are automatically mapped to corresponding ISO-MME channel codes, which removes the need for users to do this manually, saving considerable time and effort.

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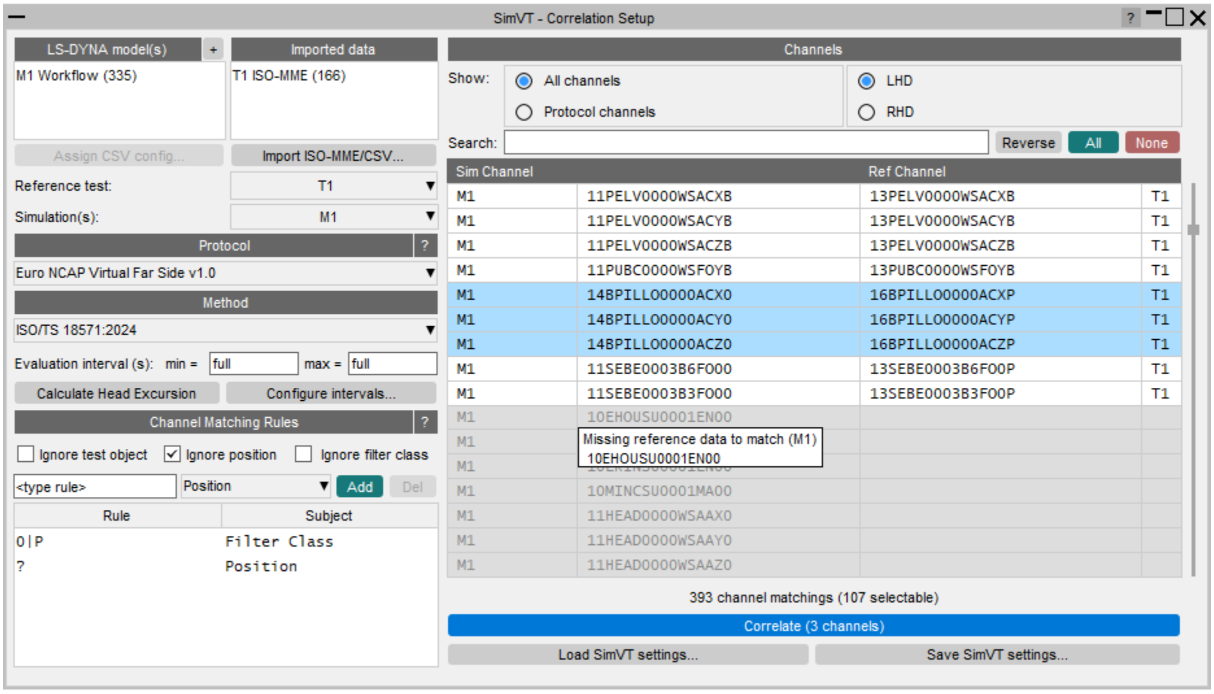

Fig.5: SimVT workflow in Oasys T/HIS showing matching and missing channels from LS-DYNA model (M1) and ISO-MME test data (T1) for the Euro NCAP Virtual Far Side v1.0 protocol, using custom channel matching rules to treat "0" and "P" filter class codes as equivalent and to ignore the ISO-MME position code.

4.3.2 SimVT for Virtual Testing

SimVT can be configured to meet the requirements specific to different virtual testing protocols. Figure 6 shows the configurations that apply when the "Euro NCAP Virtual Far Side v1.0" protocol option is selected.

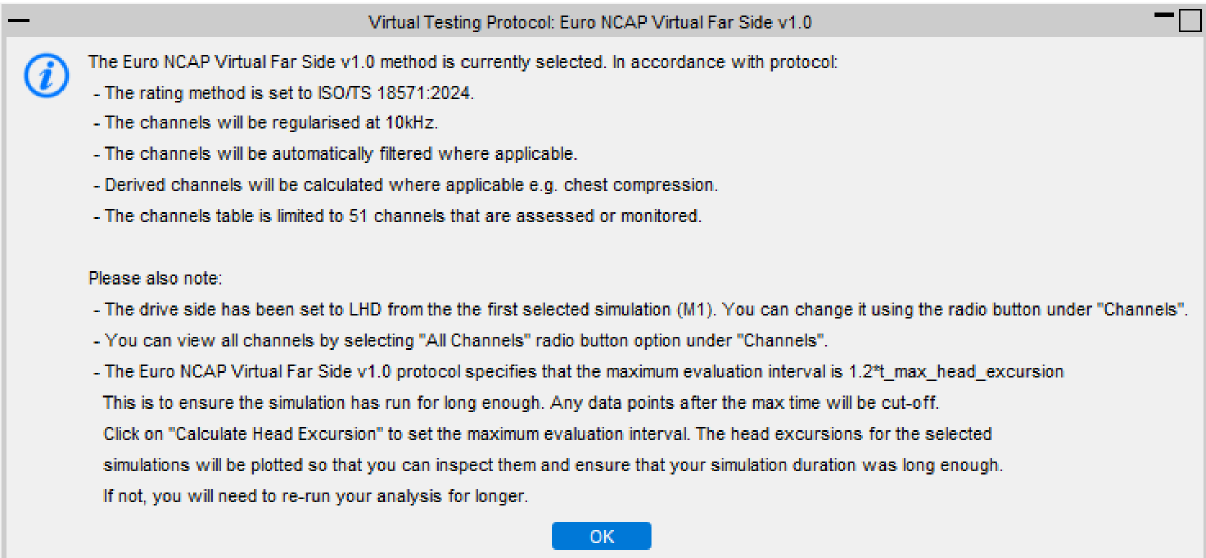

Fig.6: Information window explaining configurations that apply when the "Euro NCAP Virtual Far Side v1.0" protocol option is selected

The protocol options are provided to make it easy to use SimVT for virtual testing without having to worry about checking the protocol requirements as they are all taken care of automatically. This saves lots of time by removing the burden of interpreting the protocol and reducing associated mis-interpretation errors.

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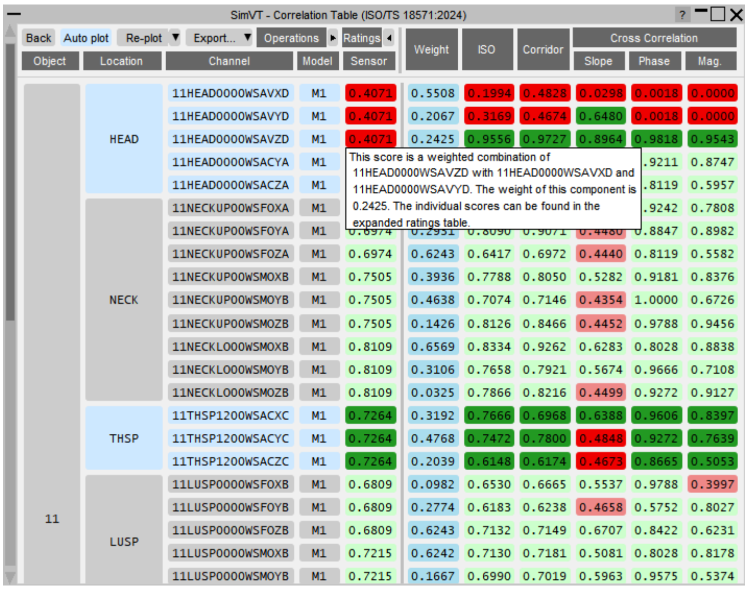
By selecting a protocol, SimVT ensures that the relevant channels are correlated correctly and that they are pre-processed by regularizing and filtering them according to that protocol's requirements. SimVT users can select the "Protocol channels" option to ensure that only channels specific to the protocol are listed, checked and processed. Flexibility is also provided to process additional channels of interest.

To meet protocol requirements, some of the channels which are correlated are derived from other channels. SimVT automatically processes any such derived channels provided that the input channels exist. For example, the Euro NCAP protocol [4] specifies that the rib compression curves are derived from the elongation and rotation curves according to the equations in TB 021 [10] before being correlated. SimVT automatically derives the rib compression curves. Similarly, the C-NCAP protocol [5] specifies that the head offset Y and Z components should be correlated and SimVT automatically derives the head offset curves from the head and b-pillar acceleration and angular velocity curves when the C-NCAP protocol option is selected.

After correlating the protocol channels, the correlation results for sensors are automatically weighted and scored according to the protocol requirements (e.g. Validation Criterion 1 (VC1) "ISO Scores" in section 6.3.5 of the Euro NCAP protocol [4], and "correlation fitting results" in sections H.1.2.1.3 and H.1.2.2.2 of the C-NCAP protocol [5]). In the SimVT Correlation Table (Fig.7:), sensors which pass the criteria appear with their scores in green, but if they fail to meet the criteria, they will appear in red which makes it easy to identify the channels which correlate poorly.

4.3.3 Correlation Table – ratings and scores

Once the correlation settings and channels have been selected, the correlation can be performed, and the results are presented in the SimVT Correlation Table.



Object	Location	Channel	Model	Sensor	Weight	ISO	Corridor	Cross Correlation Slope	Cross Correlation Phase	Cross Correlation Mag.
11	HEAD	11HEAD0000WSAVXD	M1	0.4071	0.5508	0.1994	0.4828	0.0298	0.0018	0.0000
		11HEAD0000WSAVYD	M1	0.4071	0.2067	0.3169	0.4674	0.6480	0.0018	0.0000
		11HEAD0000WSAVZD	M1	0.4071	0.2425	0.9556	0.9727	0.8964	0.9818	0.9543
		11HEAD0000WSACYA	M1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9211	0.8747
		11HEAD0000WSACZA	M1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8119	0.5957
	NECK	11NECKUP00WSFOXA	M1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9242	0.7808
		11NECKUP00WSFOYA	M1	0.6974	0.2931	0.8090	0.9071	0.4480	0.8847	0.8982
		11NECKUP00WSFOZA	M1	0.6974	0.6243	0.6417	0.6972	0.4440	0.8119	0.5582
		11NECKUP00WSMOXB	M1	0.7505	0.3936	0.7788	0.8050	0.5282	0.9181	0.8376
		11NECKUP00WSMOYB	M1	0.7505	0.4638	0.7074	0.7146	0.4354	1.0000	0.6726
		11NECKUP00WSMOZB	M1	0.7505	0.1426	0.8126	0.8466	0.4452	0.9788	0.9456
		11NECKLO00WSMOXB	M1	0.8109	0.6569	0.8334	0.9262	0.6283	0.8028	0.8838
		11NECKLO00WSMOYB	M1	0.8109	0.3106	0.7658	0.7921	0.5674	0.9666	0.7108
		11NECKLO00WSMOZB	M1	0.8109	0.0325	0.7866	0.8216	0.4499	0.9272	0.9127
	THSP	11THSP1200WSACXC	M1	0.7264	0.3192	0.7666	0.6968	0.6388	0.9606	0.8397
		11THSP1200WSACYC	M1	0.7264	0.4768	0.7472	0.7800	0.4848	0.9272	0.7639
		11THSP1200WSACZC	M1	0.7264	0.2039	0.6148	0.6174	0.4673	0.8665	0.5053
	LUSP	11LUSP0000WSFOXB	M1	0.6809	0.0982	0.6530	0.6665	0.5537	0.9788	0.3997
		11LUSP0000WSFOYB	M1	0.6809	0.2774	0.6183	0.6238	0.4658	0.5752	0.8027
		11LUSP0000WSFOZB	M1	0.6809	0.6243	0.7132	0.7149	0.6707	0.8422	0.6231
		11LUSP0000WSMOXB	M1	0.7215	0.6242	0.7130	0.7181	0.5081	0.8028	0.8178
		11LUSP0000WSMOYB	M1	0.7215	0.1667	0.6990	0.7019	0.5963	0.9575	0.5374

Fig.7: SimVT Correlation Table showing mandatory and monitored weighted sensor scores and with the ratings columns expanded to show the breakdown of individual rating scores

By default, the Correlation Table shows just the weighted sensor scores, but the table can be expanded to show the breakdown of individual rating scores. The scores are shown in green and red to indicate good and poor correlation respectively. If a virtual testing protocol has been selected, then the ISO Scores for the monitored channels are shown in pale red or green, whereas the mandatory channels are shown in bold colors to aid rapid interpretation.

By toggling their entries in the table, the correlation graphs can be plotted individually or in groups based on their location or object channel codes (Fig.8:).

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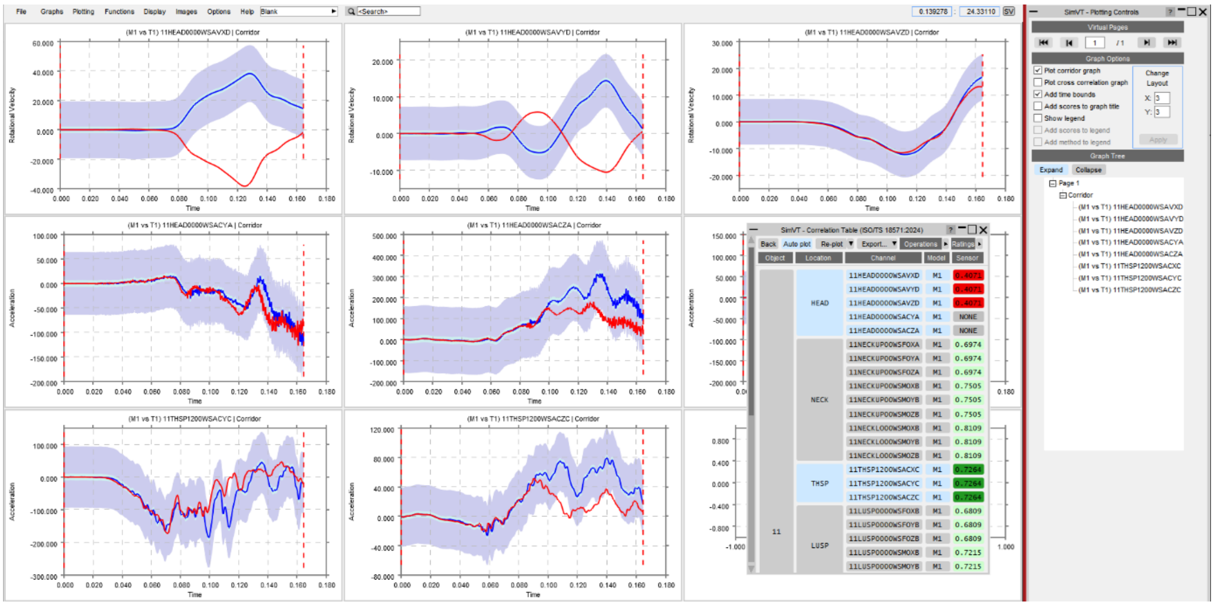
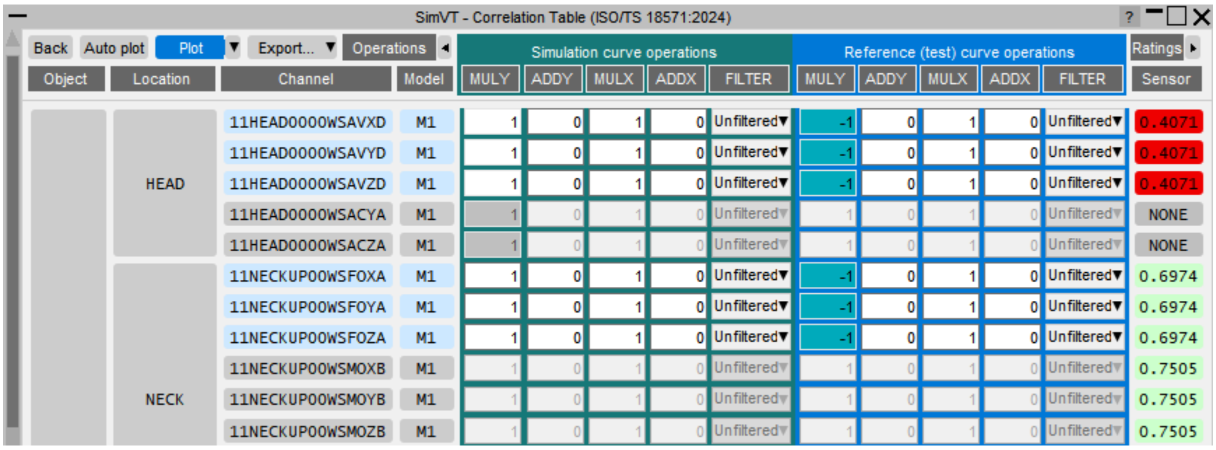


Fig.8: SimVT in Oasys T/HIS: the head and thoracic spine channels are selected in the Correlation Table and the corresponding corridor graphs are plotted

4.3.4 Correlation Table – corrective operations

When inspecting some of the correlation graphs, it may become apparent that the simulation and reference curves have adopted a different sign convention or unit system and hence they need to be corrected. SimVT makes it easy to apply such corrective operations to multiple channels at once by expanding the Operations menu to reveal a set of operations fields. Operations can be used to scale and offset the X and Y axes as well as to apply additional filtering.



SimVT - Correlation Table (ISO/TS 18571:2024)

Object	Location	Channel	Model	Sim. MULY	Sim. ADDY	Sim. MULX	Sim. ADDX	Sim. FILTER	Ref. MULY	Ref. ADDY	Ref. MULX	Ref. ADDX	Ref. FILTER	Sensor
	HEAD	11HEAD0000WSAVXD	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.4071
		11HEAD0000WSAVYD	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.4071
		11HEAD0000WSAVZD	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.4071
		11HEAD0000WSACYA	M1	1	0	1	0	Unfiltered	1	0	1	0	Unfiltered	NONE
		11HEAD0000WSACZA	M1	1	0	1	0	Unfiltered	1	0	1	0	Unfiltered	NONE
	NECK	11NECKUP00WSFOXA	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.6974
		11NECKUP00WSFOYA	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.6974
		11NECKUP00WSFOZA	M1	1	0	1	0	Unfiltered	-1	0	1	0	Unfiltered	0.6974
		11NECKUP00WSMOXB	M1	1	0	1	0	Unfiltered	1	0	1	0	Unfiltered	0.7505
		11NECKUP00WSMOYB	M1	1	0	1	0	Unfiltered	1	0	1	0	Unfiltered	0.7505
		11NECKUP00WSMOZB	M1	1	0	1	0	Unfiltered	1	0	1	0	Unfiltered	0.7505

Fig.9: Applying corrective operations to invert the y-axis for all selected reference curves at once

4.3.5 Graph options and plotting controls

By default, SimVT displays only the corridor correlation graphs, since they are typically easier to interpret and provide more value in indicating where the simulation deviates from the reference channels. However, for added flexibility, SimVT provides the option to show the cross-correlation graphs, as well as control over visibility of the graph's legend and scoring information. The graph layout can also be configured to aid quicker side-by-side comparison. The graph tree can be used to highlight a graph, helping to locate and quickly inspect results of interest (Fig.10:).

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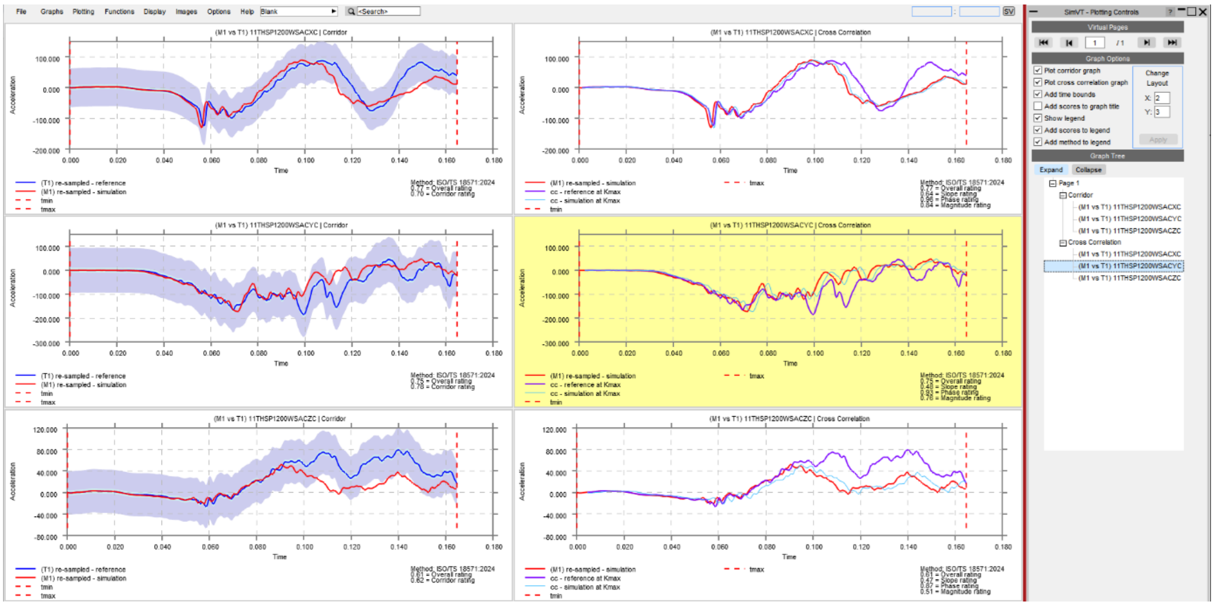


Fig.10: Corridor and cross-correlation graphs generated by SimVT, with scoring information visible in each graph legend. The thoracic spine Y acceleration cross-correlation graph has been highlighted by selecting it from the graph tree.

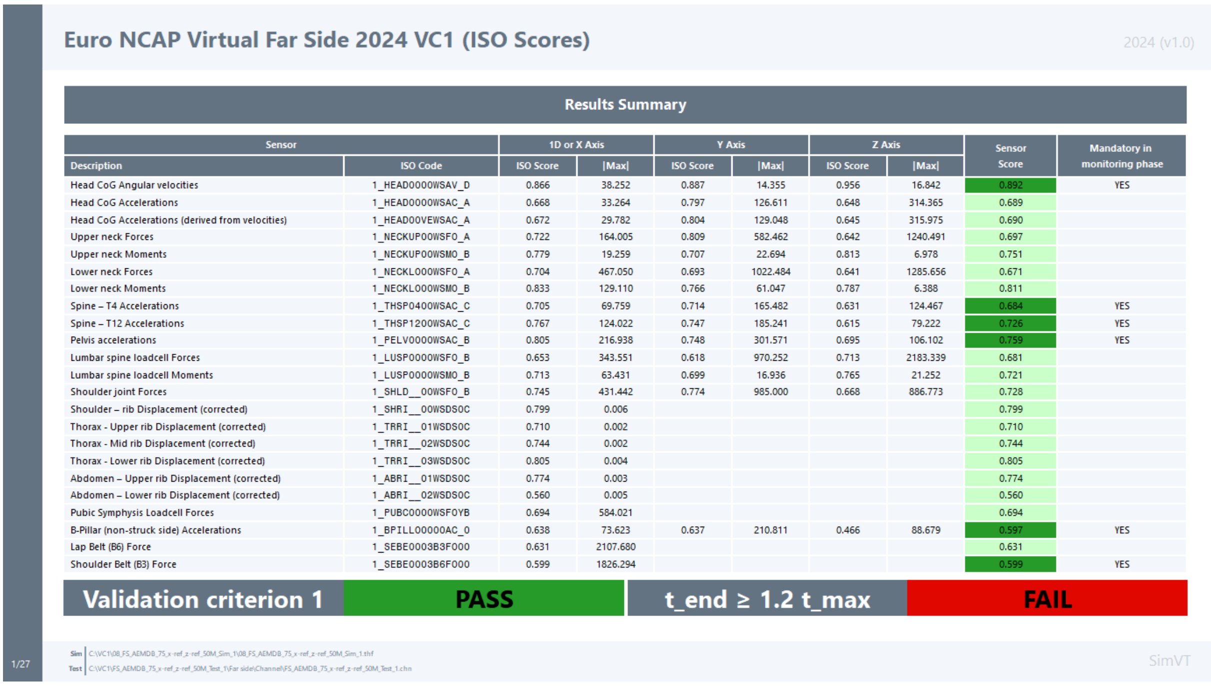
4.3.6 Exporting results and settings

The correlation results can be exported to a CSV file for further processing and record-keeping.

CAE and vehicle safety teams will need to perform large quantities of correlation analysis during virtual testing. To help manage this, a SimVT settings file can be exported to save the SimVT session settings. The SimVT settings file can then be loaded into a new SimVT session to restore the settings and channel selections again. This can save a lot of time, and the settings files can be repurposed for other simulation and test models, as well as providing the basis for automated reporting with Oasys REPORTER.

4.3.7 Automation

The power of SimVT can be leveraged via Oasys REPORTER to automatically generate virtual testing reports. For example, the Euro NCAP Virtual Far Side VC1 (ISO Scores) REPORTER template generates a report summarizing the sensor scores for all the mandatory and monitored channels required by the Euro NCAP protocol [4], as well as the correlation graphs for each channel (Fig.11: and Fig.12:). Additionally, a SimVT settings file is generated automatically and can be loaded into SimVT in Oasys T/HIS to interrogate the reported results interactively.



Euro NCAP Virtual Far Side 2024 VC1 (ISO Scores) 2024 (v1.0)

Results Summary

Sensor		1D or X Axis		Y Axis		Z Axis		Sensor Score	Mandatory in monitoring phase
Description	ISO Code	ISO Score	|Max|	ISO Score	|Max|	ISO Score	|Max|		
Head CoG Angular velocities	1_HEAD0000WSAV_D	0.866	38.252	0.887	14.355	0.956	16.842	0.892	YES
Head CoG Accelerations	1_HEAD0000WSAC_A	0.668	33.264	0.797	126.611	0.648	314.365	0.689	
Head CoG Accelerations (derived from velocities)	1_HEAD00VEWSAC_A	0.672	29.782	0.804	129.048	0.645	315.975	0.690	
Upper neck Forces	1_NECKUP00WSF0_A	0.722	164.005	0.809	582.462	0.642	1240.491	0.697	
Upper neck Moments	1_NECKUP00WSM0_B	0.779	19.259	0.707	22.694	0.813	6.978	0.751	
Lower neck Forces	1_NECKLO00WSF0_A	0.704	467.050	0.693	1022.484	0.641	1285.656	0.671	
Lower neck Moments	1_NECKLO00WSM0_B	0.833	129.110	0.766	61.047	0.787	6.388	0.811	
Spine – T4 Accelerations	1_THSP0400WSAC_C	0.705	69.759	0.714	165.482	0.631	124.467	0.684	YES
Spine – T12 Accelerations	1_THSP1200WSAC_C	0.767	124.022	0.747	185.241	0.615	79.222	0.726	YES
Pelvis accelerations	1_PELV0000WSAC_B	0.805	216.938	0.748	301.571	0.695	106.102	0.759	YES
Lumbar spine loadcell Forces	1_LUSP0000WSF0_B	0.653	343.551	0.618	970.252	0.713	2183.339	0.681	
Lumbar spine loadcell Moments	1_LUSP0000WSM0_B	0.713	63.431	0.699	16.936	0.765	21.252	0.721	
Shoulder joint Forces	1_SHLD__00WSF0_B	0.745	431.442	0.774	985.000	0.668	886.773	0.728	
Shoulder – rib Displacement (corrected)	1_SHRI__00WSDS0C	0.799	0.006					0.799	
Thorax - Upper rib Displacement (corrected)	1_TRRI__01WSDS0C	0.710	0.002					0.710	
Thorax - Mid rib Displacement (corrected)	1_TRRI__02WSDS0C	0.744	0.002					0.744	
Thorax - Lower rib Displacement (corrected)	1_TRRI__03WSDS0C	0.805	0.004					0.805	
Abdomen – Upper rib Displacement (corrected)	1_ABRI__01WSDS0C	0.774	0.003					0.774	
Abdomen – Lower rib Displacement (corrected)	1_ABRI__02WSDS0C	0.560	0.005					0.560	
Pubic Symphysis Loadcell Forces	1_PUBC0000WSF0YB	0.694	584.021					0.694	
B-Pillar (non-struck side) Accelerations	1_BPILL00000AC_0	0.638	73.623	0.637	210.811	0.466	88.679	0.597	YES
Lap Belt (B6) Force	1_SEBE0003B3F000	0.631	2107.680					0.631	
Shoulder Belt (B3) Force	1_SEBE0003B6F000	0.599	1826.294					0.599	YES

Validation criterion 1	PASS	t_end ≥ 1.2 t_max	FAIL

1/27

Sim C:\VC1\08_FS_AEMDB_75_x-ref_z-ref_50M_Sim_1\08_FS_AEMDB_75_x-ref_z-ref_50M_Sim_1.thf

Test C:\VC1\FS_AEMDB_75_x-ref_z-ref_50M_Test_1\Far side\Channel\FS_AEMDB_75_x-ref_z-ref_50M_Test_1.chn

SimVT

Fig.11: Summary page of the Euro NCAP Validation Criterion 1 report generated by Oasys REPORTER showing the protocol's mandatory and monitored sensor scores

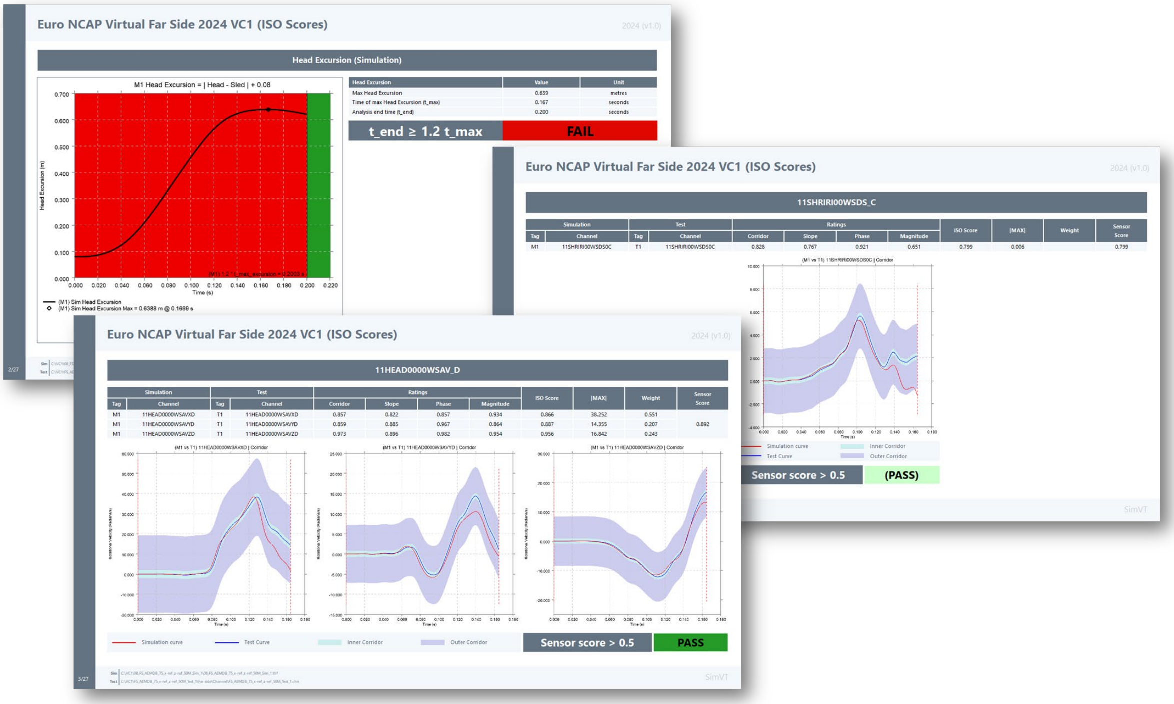


Fig.12: Example pages from the Euro NCAP Validation Criterion 1 report showing the head excursion check and correlation graphs generated by Oasys REPORTER

4.4 Injury Assessment

As with conventional occupant safety protocols, the injury criteria for different occupant body regions can be assessed using the Automotive Assessments workflow in the Oasys LS-DYNA Environment. In addition, these metrics need to be compared between simulation and physical data as part of the validation requirements described in section 3.1.3.

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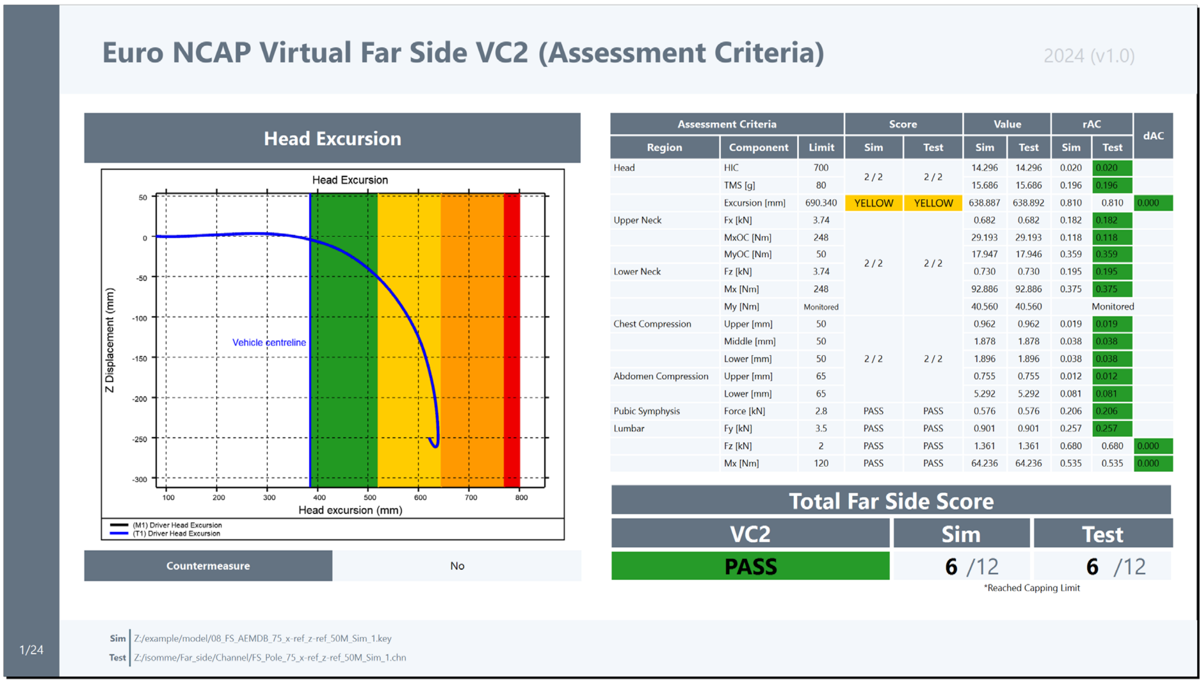
In the post-processor Oasys T/HIS, physical test data can be imported in ISO-MME or CSV format and used as the reference for the validation calculation. The ratios of injury metrics to their limits can be inspected along with graphs for detailed investigation. The calculation process can be automated with Oasys REPORTER, which produces a summary of the overall score, a clear indication of whether the validation criterion has been met, along with a visualization of the head excursion, a key metric for far side impact tests.



Assessment Criteria			Score		Value		rAC		dAC
Region	Component	Limit	Sim	Test	Sim	Test	Sim	Test	
Head	HIC	700	2 / 2	2 / 2	14.296	14.296	0.020	0.020	
	TMS [g]	80			15.686	15.686	0.196	0.196	
	Excursion [mm]	690.340	YELLOW	YELLOW	638.887	638.892	0.810	0.810	0.000
Upper Neck	Fx [kN]	3.74	2 / 2	2 / 2	0.682	0.682	0.182	0.182	
	MxOC [Nm]	248			29.193	29.193	0.118	0.118	
	MyOC [Nm]	50			17.947	17.946	0.359	0.359	
Lower Neck	Fz [kN]	3.74			0.730	0.730	0.195	0.195	
	Mx [Nm]	248			92.886	92.886	0.375	0.375	
	My [Nm]	Monitored			40.560	40.560	Monitored		
Chest Compression	Upper [mm]	50	2 / 2	2 / 2	0.962	0.962	0.019	0.019	
	Middle [mm]	50			1.878	1.878	0.038	0.038	
	Lower [mm]	50			1.896	1.896	0.038	0.038	
Abdomen Compression	Upper [mm]	65			0.755	0.755	0.012	0.012	
	Lower [mm]	65			5.292	5.292	0.081	0.081	
Pubic Symphysis	Force [kN]	2.8	PASS	PASS	0.576	0.576	0.206	0.206	
Lumbar	Fy [kN]	3.5	PASS	PASS	0.901	0.901	0.257	0.257	
	Fz [kN]	2	PASS	PASS	1.361	1.361	0.680	0.680	0.000
	Mx [Nm]	120	PASS	PASS	64.236	64.236	0.535	0.535	0.000

Fig.13: Summary page of the Euro NCAP Validation Criterion 2 report generated by Oasys REPORTER

4.5 Data Submission

Two solutions were developed specifically to meet the data submission requirements of the virtual testing protocols:

4.5.1 LS-DYNA to ISO-MME

In the Oasys LS-DYNA Environment, an “LS-DYNA to ISO-MME” workflow tool was developed to help CAE and vehicle safety teams convert LS-DYNA results into the ISO-MME format [7] specified in the Euro NCAP protocol [4]. It can also be used to convert relevant LS-DYNA outputs to ISO-MME for other protocols, such as C-NCAP, so that CAE teams can store all their virtual testing data in a consistent format.

In Oasys PRIMER, user data saved previously via the Automotive Assessments workflow removes the need for users to map LS-DYNA entities to ISO-MME channel codes manually, saving considerable time and effort. Appendix 1 Sections 1.2 and 1.3 of the Euro NCAP protocol specify mandatory header requirements for the multimedia exchange (MME) files and individual channel files. In Oasys PRIMER and Oasys T/HIS, user interfaces are provided to allow the header information to be saved as user data associated with the LS-DYNA model, so that it can be conveniently reused for repeated loadcases and reruns. In addition, Oasys PRIMER and Oasys T/HIS can scan the LS-DYNA keyword files and d3hsp file to populate the required solver and simulation information, including **`*CONTACT`** and model mass properties.

CAE teams can use Oasys REPORTER to automate the LS-DYNA to ISO-MME workflow for each LS-DYNA job. Along with the ISO-MME files, a report is generated to summarize the header information included in the files and to report any missing input data that prevented any individual channel files from being written. Oasys T/HIS can be used to perform the conversion interactively and to pinpoint and

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resolve any omissions in the LS-DYNA model setup, to ensure that the resulting ISO-MME files contain all the data required, in the correct format, ready to upload to the Euro NCAP VTC server [11].

As well as providing a solution to the challenge of quality and format of data, the LS-DYNA to ISO-MME workflow helps CAE and vehicle safety teams to work together to manage large volumes of data in a consistent, mutually accessible format. By adopting ISO-MME as an interchange format, the converted LS-DYNA results can also be used for simulation-to-simulation correlation analysis during the vehicle design process, with both SimVT and Automotive Assessments workflows accepting ISO-MME files as the reference source for the Euro NCAP VC1 and VC2 calculations, and for the C-NCAP correlation and correction factor calculations.

Fig.14: LS-DYNA to ISO-MME report generated by Oasys REPORTER to ensure correct preparation of ISO-MME files for submission to the Euro NCAP server

4.5.2 Videos

In the Oasys LS-DYNA Environment, the Euro NCAP and C-NCAP VTC Videos workflow tools help CAE teams to calculate the views and export the videos specified in Section 5.2.1 of the Euro NCAP protocol [4] and in Table H.8 of the C-NCAP protocol [5].

Both protocols require the submission of videos showing animations of the simulations from a specified set of camera angles. In Oasys PRIMER, the correct camera position, angle, and perspective for each view is predetermined automatically from the location of selected LS-DYNA model entities. This saves CAE teams significant time compared with setting up each view manually from scratch. Once the analysis job is complete, LS-DYNA users can refine the camera positions as required in post-processor Oasys D3PLOT and save them for future use. Users can also set the video start time, and end time, as well as a quality setting to control video file size. This saves further time by removing the need to redefine the views and settings each time video files need to be exported.

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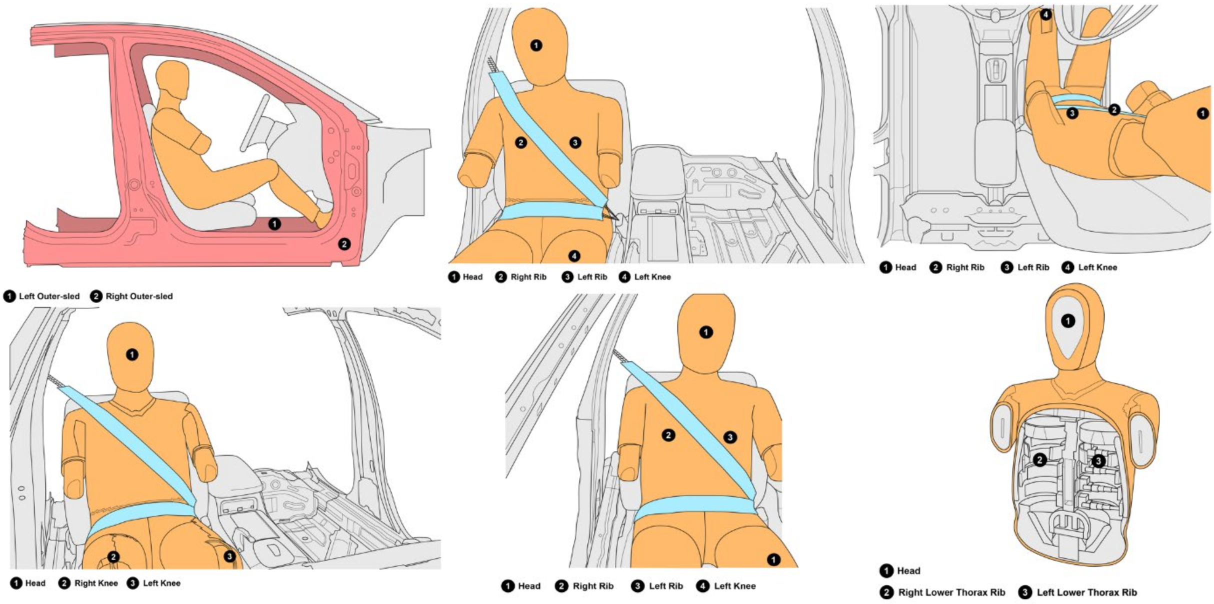

Fig.15: Oasys PRIMER uses the labelled LS-DYNA entities to predetermine the six video views required by the Euro NCAP protocol

Once the views have been saved, the video file generation process can be automated using Oasys REPORTER. The videos themselves are written as MP4 files with H.264 encoding. An accompanying report is generated containing a summary of all the videos to aid rapid checking, as well as individual pages for each video to facilitate any quick edits that may be required.

The VTC Videos workflows tools help CAE teams create virtual testing results files of the required format and quality, saving time and effort.

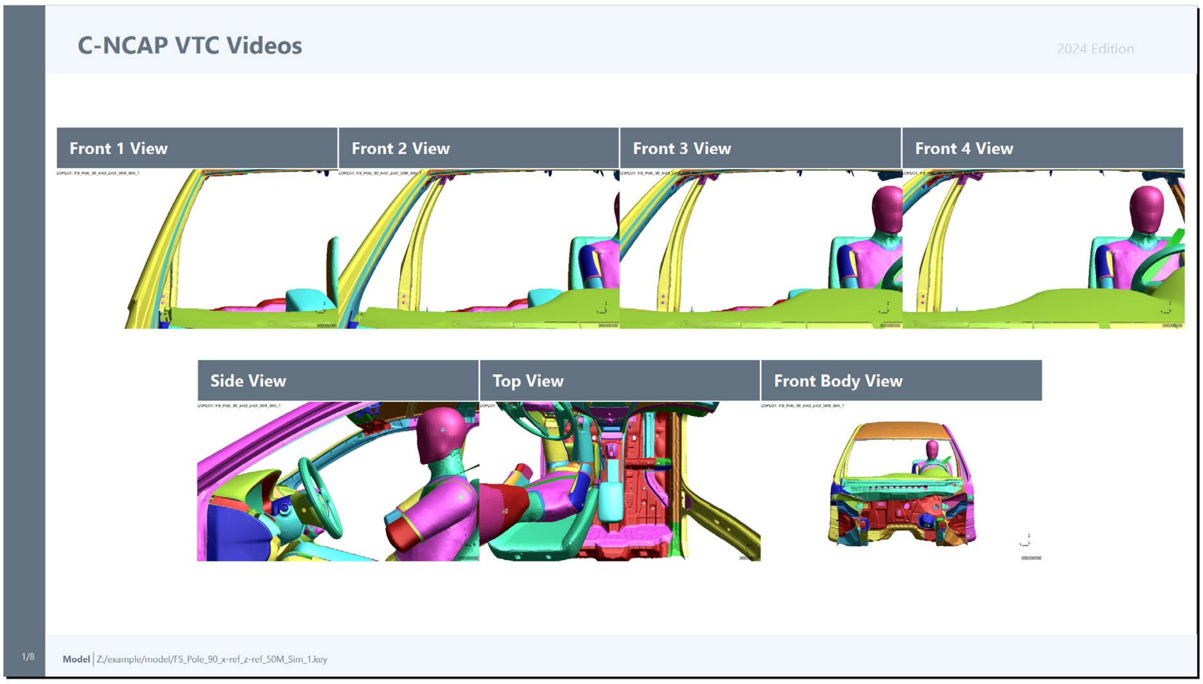

Fig.16: Summary page of the C-NCAP VTC Videos report generated by Oasys REPORTER

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5 Summary

The Virtual Testing workflow tools in the Oasys LS-DYNA Environment provide powerful and time-saving solutions for CAE and vehicle safety teams, ensuring they can meet the protocol requirements of LS-DYNA model quality, correlation assessment, injury assessment, and data submission.

Using the Automotive Assessments tool, Oasys LS-DYNA Environment users can define Workflow user data once for a vehicle program, allowing them to manage efficiently the increased quantity of LS-DYNA analysis required for virtual testing.

With the LS-DYNA to ISO-MME workflow, automatic mapping between LS-DYNA entities and ISO-MME channel codes saves time and reduces human error. Header-information-gathering and error-trapping features ensure the correct format and quality of data for submission, and a consistent ISO-MME format aids collaboration between CAE and vehicle safety teams.

SimVT solves the challenge of achieving good correlation between LS-DYNA simulation and physical test. With SimVT, Oasys LS-DYNA Environment users can view reports of correlation results with ease, using the time-saving templates preconfigured for each protocol. By using SimVT's options to process time-history data stored in a range of formats, both CAE and vehicle safety teams can use SimVT to interrogate correlation results in detail, and work together to identify any changes needed to ensure targets are achieved.

The VTC Quality Criteria workflow tools in the Oasys LS-DYNA Environment enable CAE teams to monitor and address the quality of their LS-DYNA models with confidence, and the VTC Videos workflow tools help CAE teams create video files of the required format and quality, saving time and effort.

The Oasys LS-DYNA Environment supports the published Euro NCAP and C-NCAP virtual far side impact protocols, and the solutions have been developed in a way that will facilitate support for the various other protocols due to be published in the coming years. The Oasys LS-DYNA Environment will continue to grow and respond to new virtual testing challenges that emerge, working with industry to ensure that Oasys LS-DYNA Environment solutions meet the needs of CAE and vehicle safety teams in the years ahead.

6 Literature

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